Reduction of Power Consumption of Full C-band WDM Amplification by WDM Sub-banding and SDM Conversion using a High Core Count Multi-Core Amplifier

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Abstract *We propose a method for power reduction of amplification by sub-banding wideband WDM signals and using SDM conversion on the sub-bands. We demonstrated 6.6% of power reduction using a 19C-EDFA amplifying 4.8THz of signal bandwidth on the C band.*

Introduction

Multi-core fibre (MCF) transmission is being actively researched not only to increase capacity through Spatial-Dimension Multiplexing (SDM) but also to reduce the power consumption of optical repeaters through multicore amplification. Multicore amplification is attractive for optical submarine cables where power feeding is limited, and for terrestrial transmission environments where the heat exhaust efficiency is low[1]. Several research results have been reported to reduce power consumption using multicore erbium doped fibre amplifier (MC-EDFA), based on common clad pumping[2],[3]. To take advantage of the spatial dimension, using high core count amplifiers with wide cladding doped fibre offers higher efficiency[2]. Besides, reducing the amplification bandwidth also enables to increase the amplification efficiency[4] and thus to reduce the power consumption of amplification. Indeed, amplification band edges have lower gain and gain evaluation requires to adjust the output level to the lowest gain region. Nonetheless, keeping constant amplified capacity while reducing the WDM bandwidth, requires parallelization of single core amplifiers or using MC-EDFA. This approach also advocates for using a high parallelization index or high core count MC-EDFA.

Typically doped fibres in high core count MC-EDFA have wide cladding, i.e. larger than 125 µm, lengths limited to the order of 10 m and the fibre is stored in a housing; this may seem a reasonable industrial solution with these limitations. However, transmission MCF with the similar high core count and wide cladding diameter is a severe challenge for manufacturing, reliability and cabling of tens of kilometres of deployed fibre. Thus, standard cladding diameter MCF is preferable for transmission fibre[5].

Therefore, there is a gap between fibre centric system optimization and amplifier centric system optimization. The former favours a limited number of core (circa 4) in a standard cladding diameter to transmit as many WDM channels as possible while the latter favours a high number of cores in a wide cladding MC-EDFA to amplify a limited bandwidth.

In this paper, we propose a novel power efficient amplification method illustrated in Fig. 1, which is compatible with the fibre centric approach of using many WDM channels in a limited number of cores. It relies on using the amplification centric approach with high core count in a wide cladding; it consists in splitting the transmitted wide WDM bandwidth of each core into sub-bands, converting them in the SDM dimension to use more than one amplification core for each transmitted core and regrouping the sub-bands after amplification. We experimentally validate our method using a core pumped 19-core MC-EDFA showing reduction on power consumption.

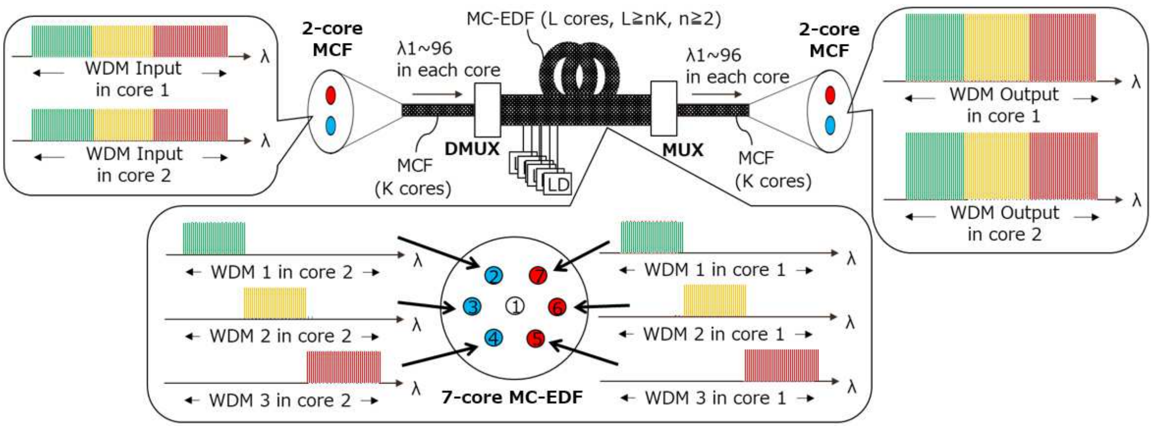

Fig. 1: Design of our proposing low-power consumption MC-EDFA

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Proposed sub-banding and SDM conversion method

Fig. 1 illustrates the proposed method. Full C band transmission is attractive from the fibre centric design perspective but amplification on the whole C band has a relatively low efficiency notably due to low gain at the band edges, leading to suppressing power in the middle of the band to equalize the gain. We take advantage of MC-EDFA centric design, which enables a high core count with wide cladding on short fibre lengths.Concretely, for a K-core MCF, the WDM signals of each core are de-multiplexed into n sub-bands with optical filters and each sub-band is output into one core of the MC-EDFA for each sub-band. The MC-EDFA must then have at least L=K×n cores. We acknowledge that one WDM channel may be lost in the sub-banding process due to the de-multiplexing filter shape but the capacity gain achieved in energy limited systems would be higher.Obviously, the SDM conversion factor n and the position of the sub-bands must be optimized to achieve reduction on power consumption.

Optimal SDM conversion and sub-banding process

In order to achieve significant reduction in power consumption, the SDM conversion factor, i.e. the number of sub-bands, as well as the sub-band widths need to be optimized. We investigated this with the experimental setup illustrated in Fig. 2 (a). 96 pseudo WDM channels of 50GHz width were generated by shaping ASE with the programmable filter of a wavelength selective switch (WSS). They occupied a total bandwidth of 4.8THz on the C band. We tested sub-banding with bundles of 12 WDM channels granularity, leading to 36 possible combinations as shown in Fig.2 (b).We used a 19-core MC-EDFA with 1480nm core pumping. The amplifier has already been reported[6]. Assuming a power efficient SDM design with low power signals spread on many spatial channels, like many pairs of 4-core MCF, and spans of 65km, the amplifier was operated with a 12 dB gain over -20 dBm/ch input.In order to start optimizing the sub-banding, we used a reference core. We first investigated assuming an ideal optical filter with no insertion loss used to generate sub-bands. Figure 3 shows the experimental results of the evaluation of the power consumption of the core pump for the central core when the SDM conversion factor n equals to 2.

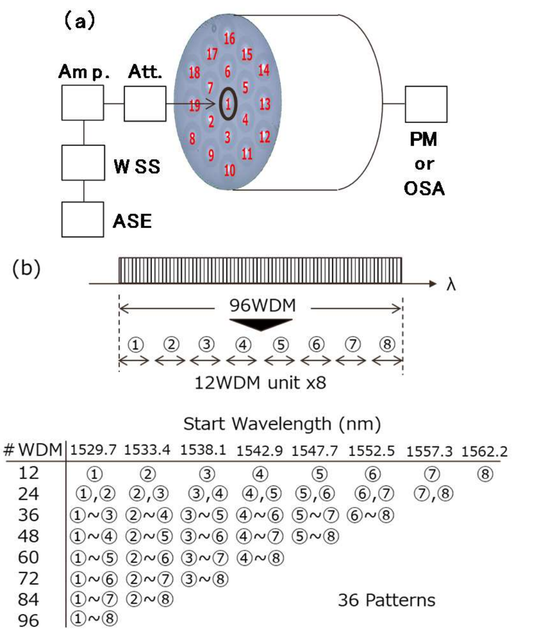

Fig. 2: (a) Experimental setup to optimize number of sub-bands and sub-band widths (b) 36 possible combinations of sub-banding

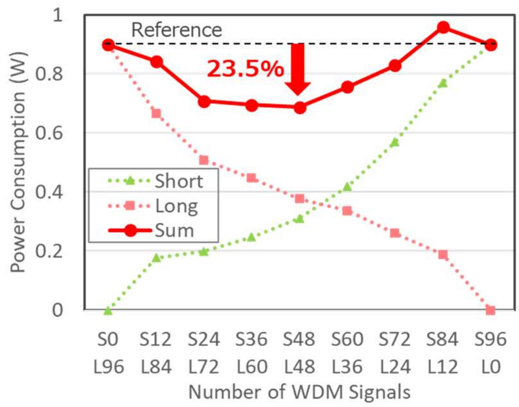

Fig. 3: Experimental results when SDM conversion factor n equals to 2.

The horizontal axis in Fig. 3 shows the number of WDM signals on each sub-band, the short wavelength side and long wavelength side, respectively. The dissymmetry on the wavelength axis originates from the shape of the gain profile of the amplifier. However, the optimal sub-banding was still obtained when the C band was split equally in its middle, enabling up to 23.5% reduction of power consumption.

We performed the same evaluation for a SDM conversion factor of n=3. Here, the dissymmetry of the gain profile against wavelength lead to an uneven WDM splitting of 36, 48 and 12 channels sub-bands from the short wavelength side to the long side. Indeed, choosing finer sub-bands leads to following in a close manner the gain profile. However, for a conversion factor of 3, the maximum reduction in power consumption was limited to 19.8%. Higher SDM conversion ratio further reduce the efficiency. We assume that the pump laser characteristics, notably its threshold current and its linearity, limit the optimal SDM conversion factor to 2. Higher conversion factors may be more efficient with other pump designs.

Another important factor in the optimization process is the insertion loss of the optical filter used to generate the sub-bands. We investigated it from the view point of the power consumption. The evaluation was performed for the SDM conversion factor cases of n=2 and 3 using the central core. The results are reported on Fig. 4. Considering the optimum SDM conversion factor n=2, the insertion loss must be kept below 0.7 dB to enable reduction in power consumption. On the other side, with ideal filtering, i.e. no insertion loss, the maximum achievable reduction of power consumption with our amplifier has an upper bound of 23.5%. Reduction of power consumption in the range of 20% require devices with insertion losses of 0.1 dB. Clearly, the development of low insertion loss devices is desired for reduction of power consumption with our scheme. In further evaluations, we used a commercially available fixed filter with an insertion loss of 0.6 dB.

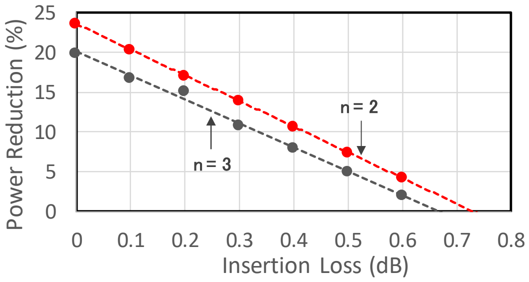

Fig. 4: Power reduction considering insertion loss

Validation of the reduction of power consumption

Finally, considering the optimal SDM conversion factor in the case n=2, we evaluated the reduction of power consumption considering 9 input SDM channels and therefore using 18 cores of the 19-core MC-EDFA. Half sub-banding was applied as we found that it was optimal. The reference was the power consumption of amplification for 96 WDM signals of the 9 SDM channels input to 9 cores of the MC-EDFA without sub-banding nor SDM conversion. We allocated the SDM channels on the 19-core MC-EDFA as shown in Fig. 5 (a) to reduce XT among neighbouring cores amplifying identical sub-bands. The core-to-core XT was therefore kept below -42.7 dB. The evaluation of the power consumption is plot on Fig. 5 (b).

Comparing the evaluation of the same SDM/WDM channels, using the fibre centric approach, i.e. 9 cores, requires more energy than using our scheme with 18 cores. Indeed, we obtained a 6.6% of power reduction, paradoxically using twice the number of cores but more efficiently. Considering our optical filter device of insertion loss of 0.6 dB, this value well agrees with the preliminary evaluation results presented in Fig.4. Therefore, we also confirmed experimentally the potential of the power reduction of our scheme, which may enable further power consumption in the range of 20% if device development enables to reduce insertion loss around 0.1 dB.

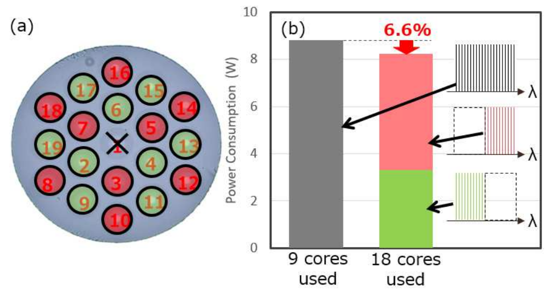

Fig. 5: Power reduction of n = 2 with 18 cores used

Conclusions

We proposed a low-power consumption MC-EDFA amplification scheme, relying on high core count MC-EDFA, which we can use to amplify wide bands WDM channels on low core count fibres. It consists in sub-banding WDM signals and using SDM conversion on the sub-bands. By using 19-core MC-EDFA, we confirmed a reduction of power consumption of 6.6% with current filtering devices with a SDM conversion factor of 2 to amplify a 4.8 THz wide bandwidth in the C band. Further device development to reduce the insertion loss of the optical filter around 0.1dB would enable a reduction of power consumption in the range of 20%.

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